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# Novel Computational Design for Designing a Modified Condenser

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***Abstract*-The most essential part of refrigeration and air conditioning is condenser because it cools the interior by transferring the internal heat of the system to surrounding using refrigerant as a medium. The Condenser design consists of copper tubes and fins of aluminium alloy 204. This current research focuses on a condenser design and compares its improvement with the recently used designs. Design adaptation is done by replacing wire fins with plates which are like arrangements of tubes running through that arrangement. Hence, condenser is a cross-flow heat exchanger which increase the heat transfer in the area exposed within its surroundings. Plate Arrangement make a channel that raise convective heat transfer coefficient and conclusively the rate of heat transfer. Conventional as well as the proposed design is a model on Solid works and this current research has employed the ANSYS technique for the analysis.. At the end, a theoretical comparison is carried out between conventional and adjusted designs to correlate the results of both designs on Finite Element Analysis (FEA) software.**

***Index Terms*- Condender, finite, convective, tubes, analysis**

## I.Introduction

A Condenser is an essential component in refrigeration and air conditioning because it provides cooling effect. It cools the interior by transferring the internal heat of the system to surrounding using refrigerant as a medium. It is typically a cross-flow of heat exchangers that provides a cooling effect with the transfer of system heat to its surroundings. Condensers are built for the cross-flow because they are most efficient heat exchangers and they remain efficient for the efficient usage of resources and pure water resources.

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Additionally, a condenser works on the principle of the condensation as its name illustrates. The refrigerant present in the tubes condenses and give its latent heat to some other medium such as water and air present in the surroundings. This suggests that the high amount of latent would automatically increase the efficiency of the condenser. For this purpose, tubes or the fins of a condenser are arranged in such a manner as to enlarge the surface area. Cooling is not only the function of a condenser but it also performs many other functions such as DE superheating, DE aeration of make-up water, provides vacuum for the existing steam and much more. All the functions mentioned above make condensers an influential part of many industries such as chemical, nuclear power plants, steam power plant, desalination petroleum, and air conditioning and much more. A condenser design and its size which is a volume parameter which differs with its application whether it is used for home-made applications or for the industrial scale.

## II.Related Work

### *A. Experimental Evidences*

Visakhapatnam [1] made his efforts in the convection heat transfer modification of AC condenser by substituting the refrigerant and by conducting CFD analysis. The tubes of refrigerant are made up of copper material and improved the fin material from pure aluminium to aluminium alloy 7075 6061. The conclusion of the results figured out that R134A had a better heat transfer coefficient and R22 gives good results of heat transfer.

Table I

Terminologies

| Term | Detail |
|---|---|
| q | Total Rate of heat transfer |
| Q | Rate of heat transfer |
| ΔT | Temperature Difference |
| A | Area of the inner surface (Hot Surface) |
| h | Convective heat transfer coefficient |
| K | Thermal Conductivity |
| L | Length of Tubes |
| $r_2$ | The outer radius of the tube |
| $r_1$ | Inner radius of the tube |
| $\Delta x$ | Thickness of plate |
| k | Thermal Conductivity of material |
| $\Delta T_m$ | Log Mean Temperature difference |
| $A_{fp}$ | Area of fin plate |
| $A_{wf}$ | Area of wire fins |

Sarntichartsak et al [2] conducted experiments on air-cooled condenser by modifying its refrigerants. A combined and distributed model was modified to

predict a better charge report. Experimental and model results were much close to each other.

The aluminium alloy 204 was used by Muhammad Yousef Pasha for the material of the fin. The thermal analysis of the condenser was conducted with ANSYS software to check the performance of the condenser. The fins angle was redesigned for improvement in the analysis. Therefore, the materials used was aluminium alloy 204, magnesium alloy, and aluminium alloy 99. The results concluded that aluminium alloy could give better results like good thermal flux, better heat transfer rate, and less thermal errors.

Refrigerant R22 produces greater heat flux therefore, the heat transfer rate is much higher in refrigerants [3]. In comparison, of copper and aluminium, the copper has better results but aluminium alloy could be used as its substitute due to its less weight.

Fin material, fin thickness, and fin spacing are the specifications that made an impact on the effectiveness of the condenser [4]. Sree lakshmi came up with a modified opinion that by decreasing the spacing between plates, the heat transfer rate increased. For the fin plates, the maximum thickness found was 0.75mm.

Different analysis software are used for the testing of magnesium alloy and aluminium alloy 6063. R404 and HCFC did as a refrigerant analysis [5]. A correspondence is found with these results and with detailed results. R404 is also used for the experimental purpose.

Mallikarjun [6] designed Ac condenser for the optimization with a variation of fin material and refrigerant. Hence, thermal and theoretical results are executed for all the materials and concluded that aluminium alloy was better for the usage of R404 as a refrigerant. CFD analysis for different fluid velocities such as 2.5m/s, 5m/s and 7.5m/s was carried out using two refrigerants R404 and HCFC. Evaluation of results declared that R404 was more desirable for the efficiency of the condenser and concluded that heat transfer rate increases with the increase of fluid velocity.

The mechanism of the disk rotation evaporator was brought for practical usage for its experimental setup [7]. Therefore, the performance evaluation was executed by developing values of evaporating temperature and frequency of the compressor. Hence, the outcomes of the direct relationship of COP with evaporating temperature would

reverse the behaviour of pressure to the compressor frequency.

Mori and Hijikata [8] worked on a vertical condenser to boast its surface geometry. The main objective was to scour out or make the thickness of outside condensate fluid as lean as possible. Hence, the analysis results indicated some factors for the enhancement of fins, moderately change in the curvature of fin, sharp edges, horizontal discs for the removal of the condensate, and wide grooves for the condensate collection.

Condenser in power plant is termed as surface condenser and it works in cycle with other components of the plant as it is an important accessory. Thermal efficiency of condenser is very small as compared to the other components which worked in the cycle but by decreasing the exhaust pressure of turbine the heat transfer rate can be increased [9]. Bhatnagar and Bartaria targeted all parameters that affect the performance of the condensers directly or indirectly.

Lau, Annamalai and Shelton identified all the fundamental parameters regarding design which are concerned for the better performance of air cooled condenser. Hence, analysis was based on some assumptions and results equation which can be applied to any air-cooled condenser.

New designs of condensers are built on the characteristics of its energy-saving process [10]. Zhu and Chen concluded that the heat transfer rate increases to 30% as compared to the traditional condensers hence, better efficiency would lead to the lower cost as well as attain the objective of energy saving.

Optimization of the refrigeration system by tausif, Patel, and Dhaval was done by modifying the shape of the condenser and refrigerant [11]. Hence, the results declared that modification which is less than the work of the compressor increases the temperature reduction that would ultimately lead to an increase the COP.

To enhance the performance of power plants it is necessary to overcome the loss of condenser designing system [12] in other words temperature increase would create the difference which is also termed as TTD (Terminal temperature difference). The enhancement was clearly identified through tube design that increased the temperature difference. The comparative study proved that the CFD tool was valid for the evaluation of condenser parameters.

Patel and Patel [13] concluded that there is a vast scope for the heat exchangers in the refrigeration and air conditioning system and if the length of the fin is increased then we could obtain more heat rejection from the condenser.

Jhariya and Gupta [14] evaluated that for single-channel condensers the cooling capacities and the COP are decreased with increase in the outdoor temperature and if the channel is doubled then the trend would remain the same but the overall efficiency of the condensers would increases by 7.1%.

Condenser is the main unit for a power plant therefore, changing the material of the fins basic material is required to increase the efficiency of the fin material. Hence by replacing the fin material higher efficiency would be achieved and the error percentage would be decreased by 2%. [15].

For fins of brazed heat exchangers aluminum alloy is a good material with enhanced corrosion resistance [16]. This material consists of core material, and some clad material on the core material. The core material consists of, weight, 0.10-1.50% Si, 0.10-0.60% Fe, 0.00-1.00% Cu, 0.70-1.80% Mn, 0.00-0.40% Mg, 0.10-3.00% Zn, 0.00-0.30% Ti, 0.00 0.30% Zr, balancing of Al and impurities. The clad material consists of, weight, 4.00-14.00% Si, 0.10-0.80% Fe, 0.00-0.50% Cu, 0.00-0.50% Mn, 0.00-0.50% Mg, 0.03 3.00% Zn, 0.00-0.30% Ti, balancing Al and impurities.

In this research old fashioned copper tube, was replaced by aluminium tubes in order to increase heat exchange [17]. The available aluminium heat exchange material products provide a high degree of compatibility with all commercially relevant with their effective costs [18]. Therefore, in this current study it is investigated the copper and Al Cu Ag are used for fin and magnesium alloy. By using aluminium alloy A199 the heat transfer rate has significantly increased.

In this research change in designing the condenser can be made by changing the point contact between tube and plate by wounding the plate on tube by the help of a line contact [19]. The analysis was done by using ANSYS 14 for the existing configuration and the results for temperature distribution were validated experimentally. By increasing the contact angle between wall and tube heat flux, and thermal gradient increased.

In this current study, the experimental results of the heat

transfer coefficient of vertical micro-fin tube condensers have been investigated [20]. Parameters such as mass flow rate and vapour quality change affecting the heat transfer coefficient are analysed along with the tube length. For the condensation experiments, two different tubes were selected for the test, namely a smooth tube and a helical micro-fin tube with refrigerant R-134a at 5.8 -5.9 bar and 10-125 kg/m2 s mass flux. These experiments of the heat transfer results showed that the helical micro-fin tube had higher Nusselt numbers at various heat flux values as compared to the smooth tube.

The present research proposed a new methodology for the simultaneous optimization of refrigerant circuiting in air-air refrigeration systems with plate-fin and tube heat exchangers [21]. This new modified methodology would prove to be more efficient than the traditional methods. This method was applied to a traditional air conditioning system, for which a COP enhancement of up to 8.34% was found. For this particular case, the refrigerant charge reduced by 28.4%, showing that this could be an efficient tool in designing an air conditioning system [22].

A study performed the optimization of single staggered wire and tube heat exchanger to increase the capacity and to reduce the mass of the heat exchanger [23]-[27]. Optimization was conducted with the Hooke-Jeeves method, which aims to optimize the geometry of the heat exchanger, especially on the diameter (dw), and the distance between wires (pw).

An increase in the number of wires (N) would also increase the heat transfer rate from heat exchanger as long as the convection coefficient is not getting influenced by the pitch fin.

### *B. Problems with Condenser Design*

Recently, used condensers have faced some flaws in its design which have stimulated the working issues of an air conditioner as well as of a refrigerator. Firstly, that the wire fins can easily bend. If a few wire coils are unable to bend during the manufacturing or operational process it would diminish the air that must pass for the proper working. Ultimately, it would constrains the cooling process. Secondly, the condenser could get jam because of the dirt present on the surface of the coil or wire fins.. Coils and condenser fins act as an insulator when a layer of dirt get

jammed on them. In this condition the refrigerant heat gets trapped in it rather than the coils to discharge it. Condensers in such conditions blow warm air that diminishes the working as well as create trouble for the external environment. Another issue which creates problem is the leakage of the refrigerant flow is in the condenser coil. That leakage reduces the amount of refrigerant and built an imbalance in the condenser.

### *C. Performance Parameters*

Parameters that affect the performance of the condenser includes conductivity, contact factor, or the area exposed to the environment and lastly dirt which reduces the coefficient performance of the condenser. So, to make an efficient condenser firstly, it requires material that would maximize the thermal conductivity with limited resources. Moreover, the heat transfer between the refrigerator and the environment would create a more efficient condenser that would increase the contact factor of the condenser. Dirt makes a layer between the wire fins and becomes an obstacle for the passing air inthe condenser which makes the condenser tube an insulator. So, to save the condenser from dust necessary changes of the design are required to at restrict the dust from getting jamming into the tube or wire fins.

Hence, heat transfer in a condenser involves two modes; conduction and convection so two laws are used further for the research.

- Newton's law of cooling
- Fourier law

These laws explain the factors that affect the rate of the heat transfer and ultimately the performance of the condenser.

Fourier law states that the heat transfer in conduction mode explains that rate of the heat transfer has direct relation with contact area, temperature difference, and with the thickness of tube wall.

$$q \propto A.\frac{\Delta T}{\Delta x}$$

$$q = K.A.\frac{\Delta T}{\Delta x}$$

Where, K is the thermal conductivity of material.

Newton's law of cooling relates to the heat transfer in convection mode and states that rate of the heat transfer has direct relation with the area and temperature differences.

$$q \propto A.\Delta T$$

$$q = h.A.\Delta T$$

Where h is termed as the convective heat transfer coefficient and depends on the velocity of the fluid.

### D. Research Objectives

This research focuses on the design characteristics of a condenser. After modifying the design of the refrigerator condenser and by replacing the wire fins with plate fins the air movement would be smoother. Both conventional with proposed designs of the same volume are modelled on solid works. To perform thermal analysis in the steady state module of ANSYS this current research employed two different models for the evaluation of the modified technique. Furthermore, the results are compared with conventional designs by using FEA (Finite Element Analysis) technique.

### E. Research Methodology

The current research follows a conventional design of refrigerator condenser which was modelled on solid works per standards [8]. Therefore, the proposed design was modelled on solid works which had the same value as a conventional design. Hence, both models are imported from ANSYS through a para file. To analyse the data thermal analysis was done on both designs to evaluate the performance of parameters. Furthermore, to evaluate the technique the theoretical FEA methods were used to compare the performance of the designs

Table I

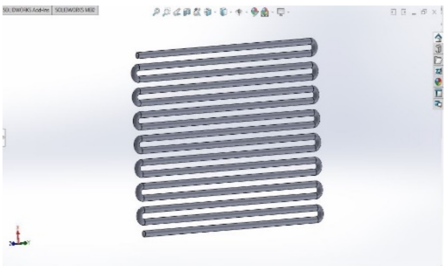
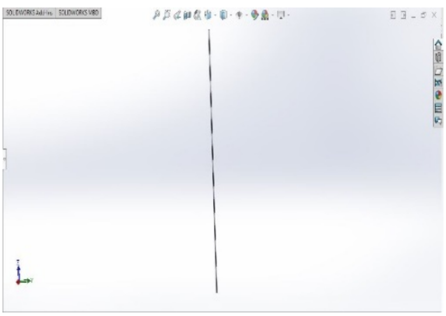
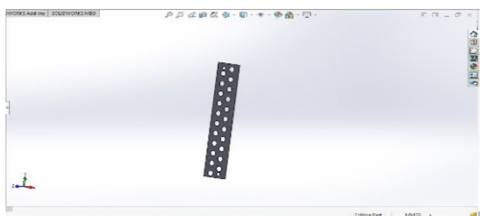
Theoretical Comparison

| Conventional Design | Modified Design |
|---|---|
| $q = U.A.\Delta T_m$ | $q = U.A.\Delta T_m$ |
| $q = \dfrac{\Delta T_m}{\frac{1}{hA} + \frac{1}{2\pi kL} ln\left(\frac{r_2}{r_1}\right) + \frac{\Delta x}{k.A} + \frac{1}{h_{air}A_{wf}}}$ | $q = \dfrac{\Delta T_m}{\frac{1}{hA} + \frac{1}{2\pi kL} ln\left(\frac{r_2}{r_1}\right) + \frac{\Delta x}{k.A} + \frac{1}{h_{air}A_{pf}}}$ |
| Since $\frac{1}{hA} + \frac{1}{2\pi kL} ln\left(\frac{r_2}{r_1}\right) + \frac{\Delta x}{k.A} = \text{constant}$ | Since $\frac{1}{hA} + \frac{1}{2\pi kL} ln\left(\frac{r_2}{r_1}\right) + \frac{\Delta x}{k.A} = \text{constant}$ |
| $q = \dfrac{\Delta T}{constant + \frac{1}{h_{air}A_{wf}}}$ | $q = \dfrac{\Delta T}{constant + \frac{1}{h_{air}A_{pf}}}$ |

- Convective heat transfer coefficient depends on the velocity of the fluid flow.
- Rework design raised the air velocity and ultimately the convective heat transfer coefficient rose.
- Combination with h expose area for the heat transfer is greater for the proposed design.
- $\frac{1}{h_{air}A_{wf}} > \frac{1}{h_{air}A_{pf}}$
- Ultimately $\frac{\Delta T}{constant+\frac{1}{h_{air}A_{pf}}} > \frac{\Delta T}{constant+\frac{1}{h_{air}A_{wf}}}$

Table II

Design Comparison

| Conventional | Modified |
|---|---|
| Tube | |
|  |  |
| Conventional | Modified |
| Fin | |
|  |  |

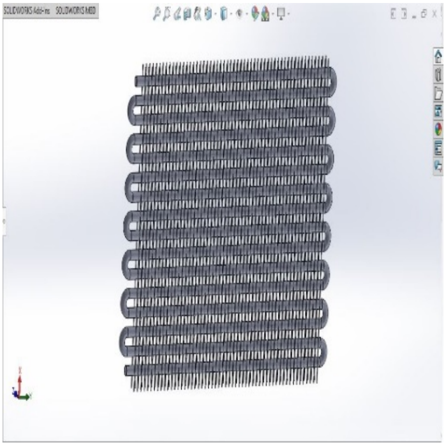
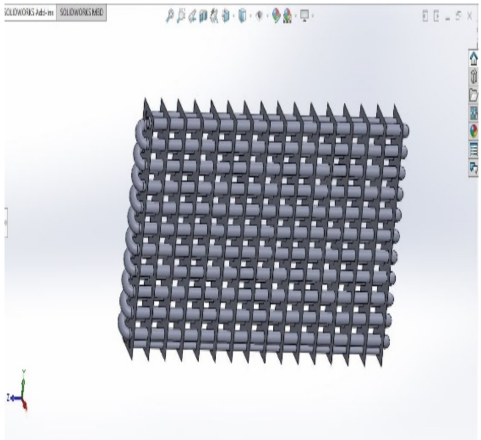
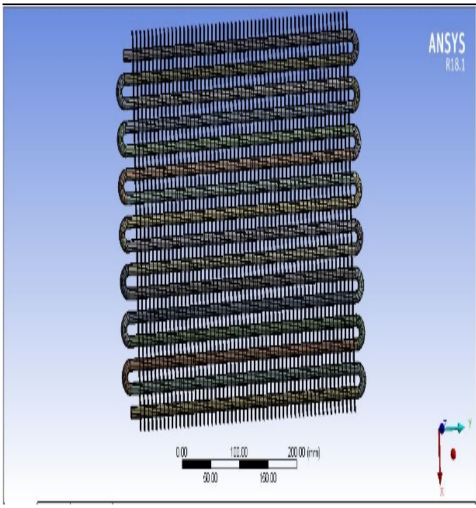
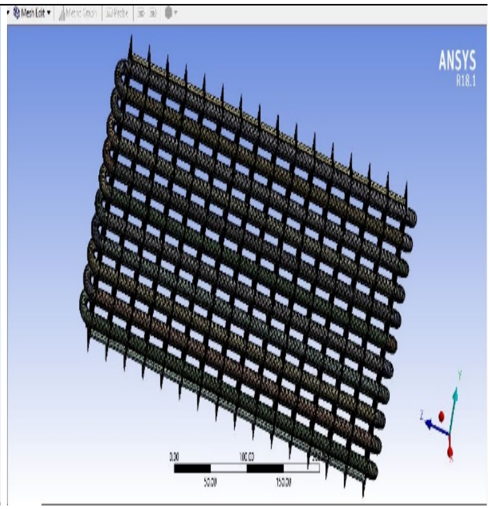
| Conventional | Modified |
|---|---|
| Final Model | |
|  |  |

Table III
Meshing and Load

| Conventional | Modified |
|---|---|
| Mesh | |
|  |  |

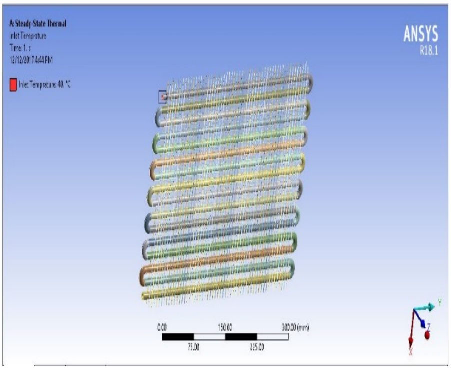
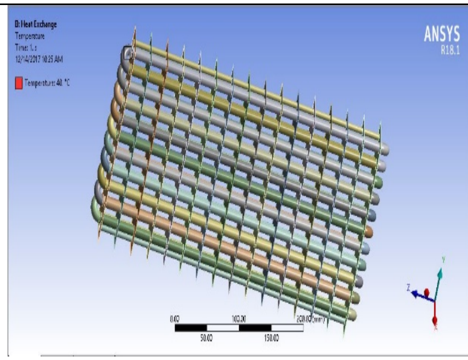
| Conventional | Modified |
|---|---|
| Load Condition | |
|   |   |

Table IV
Meshing and Load

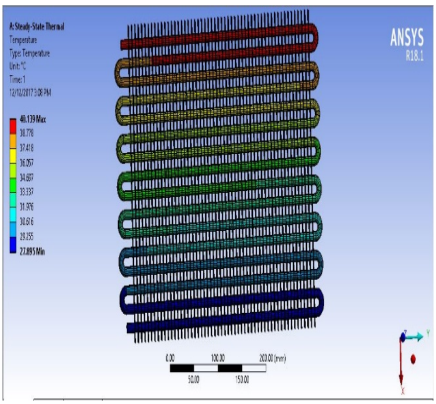
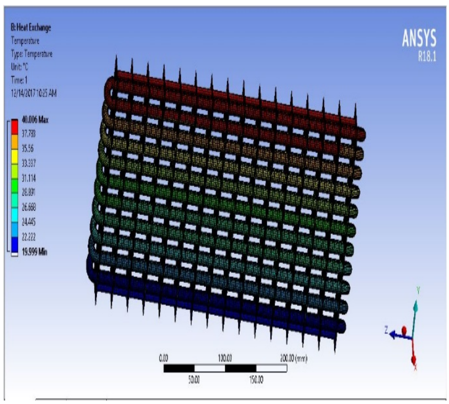
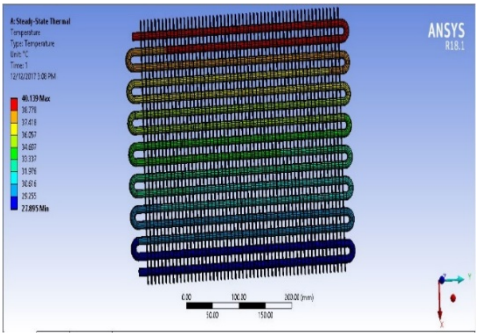
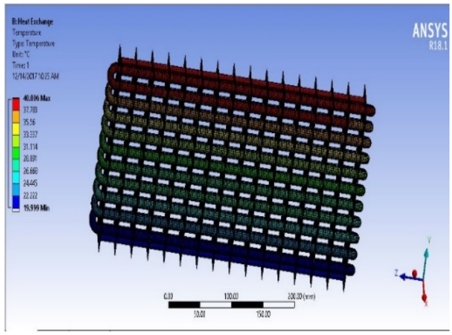
| Conventional | Modified |
|---|---|
| Temperature | |
| Max. 40.139 $^0$C | Max. 40.006 $^0$C |
| Min. 27.895 $^0$C | Min. 19.999 $^0$C |
| Gradient Produced = $m = \frac{\Delta T}{dx} = 15.305$ | Gradient Produced = $m = \frac{\Delta T}{dx} = 25.00875$ |
|   |   |

Table V

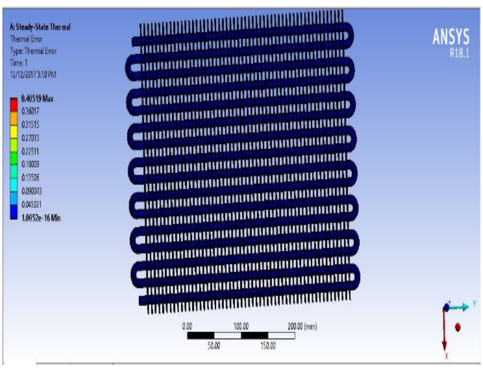
Thermal Comparison

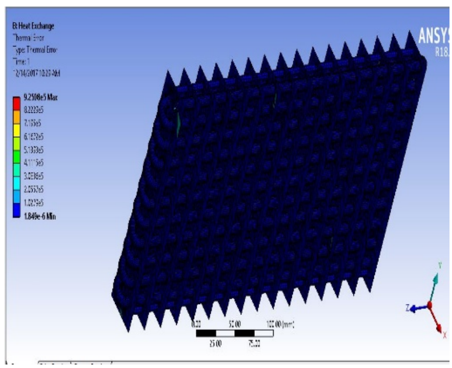
| Conventional | Modified |
|---|---|
| Temperature | |
| Max. 40.139 $^0$C<br>Min. 27.895 $^0$C<br>Gradient Produced =<br>$m = \frac{\Delta T}{dx} = 15.305$ | Max. 40.006 $^0$C<br>Min. 19.999 $^0$C<br>Gradient Produced =<br>$m = \frac{\Delta T}{dx} = 25.00875$ |

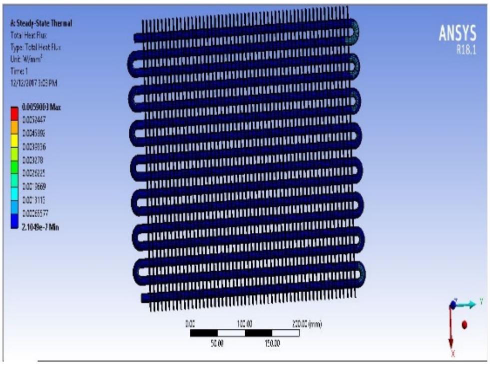
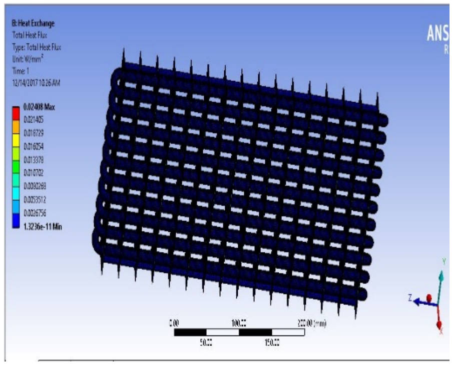
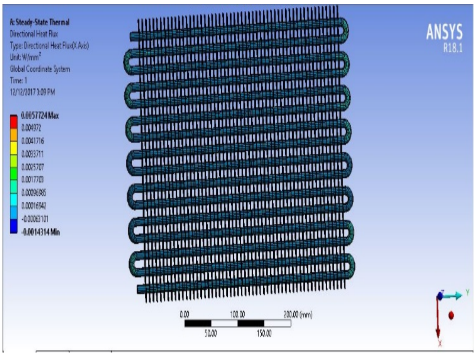
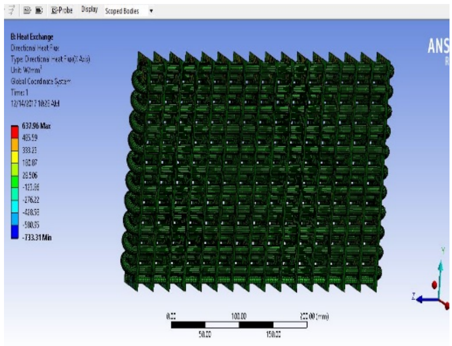



| Thermal Error | | | |
|---|---|---|---|
| Error Variations | Max. 0.40519<br>Min. 1.0052e-16 | Error Variations | Max.<br>1.0279e5<br>Min. 1.84e-6 |
| Error Produced | 1.84e-6 | Error Produced | 1.84e-6 |



| Conventional | Modified |
|---|---|
| Total Heat flux | |
| Max. 0.0059003<br>Min. 2.1049e-7 | Max. 24080<br>Min. 1.3236e-5 |
|  |  |
| Directional Heat Flux | |
| Max. 0.0057724<br>Min. -0.0014314 | Max. 637.96<br>Min. -123.86 |
|  |  |

## III.Results & Discussions

Thermal performance parameters such as temperature changes throughout the tube, heat flux, and directional heat flux are therefore, executed for both designs and results that were evaluated are compared later. Temperature gradient which was produced in proposed design was greater than the conventional design and results are tabulated as under:

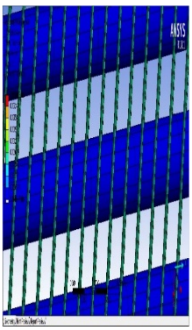
Table VI

Temperature Gratitude

| | Conventional | Modified |
|---|---|---|
| Temperature Gradient | 15.305 | 25.0088 |

Evaluation of total heat flux showed that heat flux in the conventional design was negligible in comparison to the modified design. Hence, the numerical values of heat flux for both designs are given below.

Conventional Modified



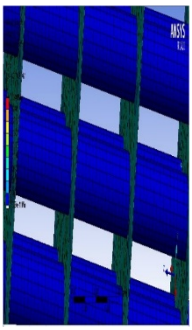


Table VII

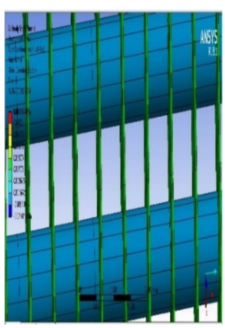
Numerical Values of Heat Flux

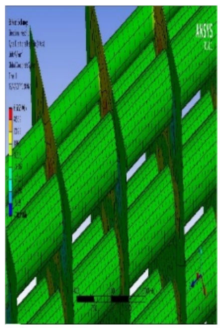
| | Conventional | | Modified | |
|---|---|---|---|---|
| Design | Max | Min | Max | Min |
| Total Heat Flux | 0.005 9003 | .2.10 49e-7 | 2408 0 | 1.323 6e-5 |

Total heat flux pattern on the fin plate were much more than the wire fins that are recently being used in condensers as shown in the Figure below. These increased number of patterns and numeric values corresponds to the development of the condenser.

Like total heat flux directional heat flux is inconsequential in conventional designs because it has a very small value. However, directional heat flux showed a significant improvement in the performance of the condenser when wire fins were replaced by plate fins and that improvement was judged by the pattern (shown in figure) which developed on the plates.

Conventional Modified





Numeric values of the above parameters are given below.

Table VIII

Numerical Values of Directional Heat Flux

| | Conventional | | Modified | |
|---|---|---|---|---|
| Design | Max. | Min | Max | Min |
| Directional Heat Flux | 0.0057724 | 0.0014314 | 637.96 | -123.9 |

All three parameters temperature, total heat flux, and directional heat flux increased significantly because total heat flux and directional heat flux are imperceptible with respect to the proposed design. Therefore, these three frameworks are the vindication of improvement that yields from the proposed design.

## IV.Conclusion

Two condenser models of the same volume usually flourished on solid works; and may consists of conventional and per rework characteristics. This paper aims to study the conventional designs of a refrigerator condenser by using Finite Element Analysis (FEA) software. Additionally, to analyse the improved performance of condenser, fin plates are recommended in condenser design for the replacement of the wire fins. Furthermore, the current study employed a theoretical comparison of two models which exposed that the better performance of the nominated condenser is judged with the usage of fin plates. The increased rise of convective heat transfer coefficient is an exceptional function of velocity. FEA comparison of the selected designs gave numeric values of the temperature gradient, total heat flux, directional heat flux, and distribution pattern of the selected parameters. Numeric values and distribution patterns provide prominent thermal gradients for the proposed design. Numeric figures of total heat flux and directional heat flux distribution and its pattern are imperceptible when correlated with customized design. So, to make changes in the condenser design modified techniques are required for better economic performance and electricity consumption because it would not require extra resources or additional materials.

## References

[1] P. Prasad, “Improving the heat transfer rate of ac condenser by optimizing material,” *Int. J. Sci. Eng. Technol. Res.*, vol. 6, no. 13, pp. 2512-2516, 2017.

[2] P. Sarntichartsak, V. Monyakul, and S. Thepa, “Conducted experiments on inverter air conditioner with variation of

capillary tube using R22 and R407C and predicted model," *Energy Convers. Manag.*, vol. 48, no. 2, pp.344-354, Feb. 2007, doi: https://doi.org/10.1016/j.enconman.2006.07.005

[3] N. Bheemesh and N. Venkateswarlu, "Design and heat transfer analysis of ac condenser for different materials," *Int. J. Magazine Eng. Technol. Manag. Res.*, vol. 2, no. 8, pp. 461-467, Aug. 2015.

[4] D. R. Babu and R. Srikanth, "Design and analysis of different material to increase the performance of AC condenser," *Int. J. Res.*, Vol 3, no.11, pp.518-547, July 2016.

[5] Mallikarjun, A. S. Malipatil, "CFD analysis of air cooled condenser by using copper tubes aluminium fins," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 2, no. X, pp. 214-226, Oct. 2014.

[6] H. Wu, Y. Li, and J. Chen, "Research on an evaporator-condenser-separated mechanical vapor compression system," *Desalination*, vol. 324, pp. 65-71, Sep. 2013, doi: https://doi.org/10.1016/j.desal.2013.06.004

[7] Y. Mori, K. Hijikata, S. Hirasawa, and W. Nakayama, "Optimized performance of condensers with outside condensing surfaces," *J. Heat Transfer.*, vol. 103, no. 1, pp. 96-102, Feb. 1981, doi: https://doi.org/10.1115/1.3244439

[8] P. Bhatnagar and V. N. Bartaria, "Surface condenser design-a review," *Int. J. Innov. Res. Develop.*, vol. 1, no. 5, pp. 438-449, 2012.

[9] S. C. Lau, K. Annamalai, and S. V. Shelton, "Optimization of air-cooled condensers," *J. Energy Resour. Technol.*, vol. 109, no. 2, pp. 90-95, June 1987, doi: https://doi.org/10.1115/1.3231331

[10] K. Zhu, X. Chen, B. Dai, Y. Wang, X. Li, and L. Li, "Experimental study on thermal performance improvement of a new designed condenser with liquid separator," *Energy Procedia*, vol. 104, pp, 269-274, Dec. 2016, doi: https://doi.org/10.1016/j.egypro.2016.12.046

[11] S. Hecker, A. Auge, T. Ellsel, J. Flegler, C. Musch, and A. Graßmann, "Performance increase of steam turbine

condensers by CFD analysis," in *ASME Turbo Expo 2014 Turbine Tech. Conf. and Exp.*, Sep. 2014, Art. no. GT2014-25812, doi: https://doi.org/10.1115/GT2014-25812

[12] A. S. Patil, A. A. Patil, and V. H. Patil, "Design and development of water cooled condenser for domestic refrigerator." *Int. J. Sci. Spir. Bus. Technol.*, vol. 4, no. 2, May 2016.

[13] M. Jhariya, P. K. Jhinge, and R. C. Gupta, "Experimental study on performance of condenser of two different types used in window air conditioner," *Int. J. Curr. Res. Aca. Rev.*, vol. 1, no. 4, pp. 45-41, 2013.

[14] S. V. Lavrinenko, P. Polikarpov, A. A. Matveeva, and V. N. Martyshev, "Modelling of heat transfer process in condensing unit with titanium alloy tubes," in *Int. Youth Sci. Conf.*, Apr. 2017, Tomsk, Russia.

[15] X.-J. Jiang, M. Syslak, J. D. Evensen, "Aluminium alloy to be used as fin material," U.S. Patent US 2005/0106410A1, May 19, 2005.

[16] V. Vekariyamukesh, G. R. Selokar, and A. Paul, "Optimization and design of heat exchanger with different materials," *IJMEMS*, vol. 5, no. 1, pp. 37-42, June 2012.

[17] V. Srividhya, G. V. Rao, "Improving the heat transfer rate for Ac condenser by material and parametric design optimization," *Int. J. Eng. Res. Technol.*, vol. 2, no. 1, Jan. 2013.

[18] D. R. Akash, N. R. Sheth, and N. C. Mehta, "Thermal analysis of hot wall condenser for domestic refrigerator," *Int. J. Sci. Res.*, vol.3, no. 7, pp, 622-626, 2014.

[19] N. Eskin, G. Arslan, "Effect of design and operation parameters on heat transfer coefficient in condensers," in *15th Int. Res. Conf. Trends Develop. Mach. Asso. Technol.*, Sep. 12-18, 2011.

[20] L. C. C. Martínez, J. A. R. Parise, S. F. Y. Motta, and E. de C. V. Becerra, "Plate-fin and tube heat exchangers refrigerant circuiting optimization in vapor compression refrigeration systems," in *Int. Refrig. Air Cond. Conf.* July 12-15, 2012.

[21] P. Padgil, S. H. Barhatte, and P. E. Choudhary, "Heat transfer enhancement in shell and tube condenser," *Int. J.*

*Curr. Eng. Technol.*, no.7, pp. Mar. 2017.

[22] I. M. Arsana, Susianto, K. Budhikarjono, and A. Altway, "Optimization of the single staggered wire and tube heat exchanger," in *3rd Bali Int. Semi. Sci. Technol.*, Art. no. 01017, May 2016, doi: https://doi.org/10.1051/mateconf/20165801017

[23] A. Giwa and S. O. Giwa, "Isopropyl myristate production process optimization using response surface methodology and MATLAB," *Int. J. Eng. Res. Technol.*, vol. 2 no. 1, pp. 853-862, Jan. 2013.

[24] C.-C. Wang, C.-J. Lee, C.-T. Chang, and Y.-J. Chang, "Some aspects of plate fin-and-tube heat exchangers with and without louvers," *J. Enhanc. Heat Trans.*, vol. 6, no. 5, pp. 357-368, 1999, doi: https://doi.org/10.1615/JEnhHeatTransf.v6.i5.30

[25] C. C. Wang, Y. P. Chi, K. Y. C. Chang, and Y. J. Chang, "An experimental study of heat transfer and friction characteristics of typical louver fin and tube heat exchangers," *Int. J. Heat Mass Trans.*, vol. 41, no. 4-5, pp. 817-822, 1998, doi: https://doi.org/10.1016/S0017-9310(97)00154-3

[26] D. B. Bivens et al., "HFC-22 Alternatives for Air Conditioners and Heat Pumps," *ASHRAE Transac.*, vol. 101, pp. 1065- 1071, 1995.

[27] V. Baxter, S. Fischer, and J. Sand, "Global warming implications of replacing ozone-depleting refrigerants," *ASHRAE J.*, vol. 40, no. 9, pp. 23-30, Sep. 1998.